CHAPTER 6

EXPOSURE ASSESSMENT

This chapter describes the procedures for conducting an exposure assessment as part of the baseline risk assessment process at Superfund sites. The objective of the exposure assessment is to estimate the type and magnitude of exposures to the chemicals of potential concern that are present at or migrating from a site. The results of the exposure assessment are combined with chemical-specific toxicity information to characterize potential risks.

The procedures and information presented in this chapter represent some new approaches to exposure assessment as well as a synthesis of currently available exposure assessment guidance and information published by EPA. Throughout this chapter, relevant exposure assessment documents are referenced as sources of more detailed information supporting the exposure assessment process.

6.1 BACKGROUND

Exposure is defined as the contact of an organism (humans in the case of health risk assessment) with a chemical or physical agent (EPA 1988a). The magnitude of exposure is determined by measuring or estimating the amount of an agent available at the exchange boundaries (i.e., the lungs, gut, skin) during a specified time period. Exposure assessment is the determination or estimation (qualitative or quantitative) of the magnitude, frequency, duration, and route of exposure. Exposure assessments may consider past, present, and future exposures, using varying assessment techniques for each phase. Estimates of current exposures can be based on measurements or models of existing conditions, those of future exposures can be based on models of future conditions, and those of past exposures can be based on measured or modeled past concentrations or measured chemical concentrations in tissues. Generally, Superfund exposure assessments are concerned with current and future exposures. If human monitoring is planned to assess current or past exposures, the Agency for Toxic Substances and Disease Registry (ATSDR) should be consulted to take the lead in conducting these studies and in assessing the current health status of the people near the site based on the monitoring results.

6.1.1 COMPONENTS OF AN EXPOSURE ASSESSMENT

The general procedure for conducting an exposure assessment is illustrated in Exhibit 6-1. This procedure is based on EPA's published *Guidelines for Exposure Assessment* (EPA 1986a) and on other related guidance (EPA 1988a, 1988b). It is an adaptation of the generalized exposure assessment process to the particular needs of Superfund site risk assessments. Although some exposure assessment activities may have been started earlier (e.g., during RI/FS scoping or even before the RI/FS process began), the detailed exposure assessment process begins after the chemical data have been collected and validated and the chemicals of potential concern have been selected (see Chapter 5, Section 5.3.3). The exposure assessment proceeds with the following steps.

ACRONYMS FOR CHAPTER 6

ATSDR = Agency for Toxic Substances and Disease Registry
BCF = Bioconcentration Factor
CDI = Chronic Daily Intake
CEAM = Center for Exposure Assessment Modeling
NOAA = National Oceanographic and Atmospheric Administration
NTGS = National Technical Guidance Studies
OAQPS = Office of Air Quality Planning and Standards
RME = Reasonable Maximum Exposure
SDI = Subchronic Daily Intake
SEAM = Superfund Exposure Assessment Manual
USGS = U.S. Geological Survey

DEFINITIONS FOR CHAPTER 6

Absorbed Dose. The amount of a substance penetrating the exchange boundaries of an organism after contact. Absorbed dose is calculated from the intake and the absorption efficiency. It usually is expressed as mass of a substance absorbed into the body per unit body weight per unit time (e.g., mg/kg-day).

Administered Dose. The mass of a substance given to an organism and in contact with an exchange boundary (e.g., gastrointestinal tract) per unit body weight per unit time (e.g., mg/kg-day).

Applied Dose. The amount of a substance given to an organism, especially through dermal contact.

Chronic Daily Intake (CDI). Exposure expressed as mass of a substance contacted per unit body weight per unit time, averaged over a long period of time (as a Superfund program guideline, seven years to a lifetime).

Contact Rate. Amount of medium (e.g., ground water, soil) contacted per unit time or event (e.g. liters of water ingested per day).

Exposure. Contact of an organism with a chemical or physical agent. Exposure is quantified as the amount of the agent available at the exchange boundaries of the organism (e.g., skin, lungs, gut) and available for absorption.

Exposure Assessment. The determination or estimation (qualitative or quantitative) of the magnitude, frequency, duration, and route of exposure.

Exposure Event. An incident of contact with a chemical or physical agent. An exposure event can be defined by time (e.g., day, hour) or by the incident (e.g., eating a single meal of contaminated fish).

Exposure Pathway. The course a chemical or physical agent takes from a source to an exposed organism. An exposure pathway describes a unique mechanism by which an individual or population is exposed to chemicals or physical agents at or originating from a site. Each exposure pathway includes a source or release from a source, an exposure point, and an exposure route. If the exposure point differs from the source, a transport/exposure medium (e.g., air) or media (in cases of intermedia transfer) also is included.

Exposure Point. A location of potential contact between an organism and a chemical or physical agent.

Exposure Route. The way a chemical or physical agent comes in contact with an organism (e.g., by ingestion, inhalation, dermal contact).

Intake. A measure of exposure expressed as the mass of a substance in contact with the exchange boundary per unit body weight per unit time (e.g., mg chemical/kg body weight-day). Also termed the normalized exposure rate equivalent to administered dose.

Lifetime Average Daily Intake. Exposure expressed as mass of a substance contacted per unit body weight per unit time, averaged over a lifetime.

Subchronic Daily Intake (SDI). Exposure expressed as mass of a substance contacted per unit body weight per unit time, averaged over a portion of a lifetime (as a Superfund program guideline, two weeks to seven years).

Step 1 -- Characterization of exposure setting (Section 6.2). In this step, the assessor characterizes the exposure setting with respect to the general physical characteristics of the site and the characteristics of the populations on and near the site. Basic site characteristics such as climate, vegetation, ground-water hydrology, and the presence and location of surface water are identified in this step. Populations also are identified and are described with respect to those characteristics that influence exposure, such as location relative to the site, activity patterns, and the presence of sensitive subpopulations. This step considers the characteristics of the current population, as well as those of any potential future populations that may differ under an alternate land use.

Step 2 -- Identification of exposure pathways (Section 6.3). In this step, the exposure assessor identifies those pathways by which the previously identified populations may be exposed. Each exposure pathway describes a unique mechanism by which a population may be exposed to the chemicals at or originating from the site. Exposure pathways are identified based on consideration of the sources, releases, types, and locations of chemicals at the site; the likely environmental fate (including persistence, partitioning, transport, and intermedia transfer) of these chemicals; and the location and activities of the potentially exposed populations. Exposure points (points of potential contact with the chemical) and routes of exposure (e.g., ingestion, inhalation) are identified for each exposure pathway.

Step 3 -- Quantification of exposure (Section 6.4). In this step, the assessor quantifies the magnitude, frequency and duration of exposure for each pathway identified in Step 2. This step is most often conducted in two stages: estimation of exposure concentrations and calculation of intakes.

Estimation of exposure concentrations (Section 6.5). In this part of step 3, the exposure assessor determines the concentration of chemicals that will be contacted over the exposure period. Exposure concentrations are estimated using monitoring data and/or chemical transport and environmental fate models. Modeling may be used to estimate future chemical concentrations in media that are currently contaminated or that may become contaminated, and current concentrations in media and/or at locations for which there are no monitoring data.

Calculation of intakes (Section 6.6). In this part of step 3, the exposure assessor calculates chemical-specific exposures for each exposure pathway identified in Step 2. Exposure estimates are expressed in terms of the mass of substance in contact with the body per unit body weight per unit time (e.g., mg chemical per kg body weight per day, also expressed as mg/kg-day). These exposure estimates are termed "intakes" (for the purposes of this manual) and represent the normalized exposure rate. Several terms common in other EPA documents and the literature are equivalent or related to intake (see box on this page and definitions box on page 6-2). Chemical intakes are calculated using equations that include variables for exposure concentration, contact rate, exposure frequency, exposure duration, body weight, and exposure averaging time. The values of some of these variables depend on site conditions and the characteristics of the potentially exposed population.

After intakes have been estimated, they are organized by population, as appropriate (Section 6.7). Then, the sources of uncertainty (e.g., variability in analytical data, modeling results, parameter assumptions) and their effect on the exposure estimates are evaluated and summarized (Section 6.8). This information on uncertainty is important to site decision-makers who must evaluate the results of the exposure and risk assessment and make decisions regarding the degree of remediation required at a site. The exposure assessment concludes with a summary of the estimated intakes for each pathway evaluated (Section 6.9).

TERMS EQUIVALENT OR RELATED TO INTAKE

Normalized Exposure Rate. Equivalent to intake

Administered Dose. Equivalent to intake

Applied Dose. Equivalent to intake

Absorbed Dose. Equivalent to intake multiplied by an absorption factor

6.1.2 REASONABLE MAXIMUM EXPOSURE

Actions at Superfund sites should be based on an estimate of the reasonable maximum exposure (RME) expected to occur under both current and future land-use conditions. The reasonable maximum exposure is defined here as the highest exposure that is reasonably expected to occur at a site. RMEs are estimated for individual pathways. If a population is exposed via more than one pathway, the combination of exposures across pathways also must represent an RME.

Estimates of the reasonable maximum exposure necessarily involve the use of professional judgment. This chapter provides guidance for determining the RME at a site and identifies some exposure variable values appropriate for use in this determination. The specific values identified should be regarded as general recommendations, and could change based on site-specific information and the particular needs of the EPA remedial project manager (RPM). Therefore, these recommendations should be used in conjunction with input from the RPM responsible for the site.

In the past, exposures generally were estimated for an average and an upper-bound exposure case, instead of a single exposure case (for both current and future land use) as recommended here. The advantage of the two case approach is that the resulting range of exposures provides some measure of the uncertainty surrounding these estimates. The disadvantage of this approach is that the upper-bound estimate of exposure may be above the range of possible exposures, whereas the average estimate is lower than exposures potentially experienced by much of the population. The intent of the RME is to estimate a conservative exposure case (i.e., well above the average case) that is still within the range of possible exposures. Uncertainty is still evaluated under this approach. However, instead of combining many sources of uncertainty into average and upper-bound exposure estimates, the variation in individual exposure variables is used to evaluate uncertainty (See Section 6.8). In this way, the variables contributing most to uncertainty in the exposure estimate are more easily identified.

6.2 STEP 1: CHARACTERIZATION OF EXPOSURE SETTING

The first step in evaluating exposure at Superfund sites is to characterize the site with respect to its physical characteristics as well as those of the human populations on and near the site. The output of this step is a qualitative evaluation of the site and surrounding populations with respect to those characteristics that influence exposure. All information gathered during this step will support the identification of exposure pathways in Step 2. In addition, the information on the potentially exposed populations will be used in Step 3 to determine the values of some intake variables.

6.2.1 CHARACTERIZE PHYSICAL SETTING

Characterize the exposure setting with respect to the general physical characteristics of the site. Important site characteristics include the following:

- climate (e.g., temperature, precipitation);
- meteorology (e.g., wind speed and direction);
- geologic setting (e.g., location and characterization of underlying strata);
- vegetation (e.g., unvegetated, forested, grassy);
- soil type (e.g., sandy, organic, acid, basic);
- ground-water hydrology (e.g., depth, direction and type of flow); and
- location and description of surface water (e.g., type, flow rates, salinity).

Sources of this information include site descriptions and data from the preliminary assessment (PA), site inspection (SI), and remedial investigation (RI) reports. Other sources include county soil surveys, wetlands maps, aerial photographs, and reports by the National Oceanographic and Atmospheric Association (NOAA) and the U.S. Geological Survey (USGS). The assessor also should consult with appropriate technical experts (e.g., hydrogeologists, air modelers) as needed to characterize the site.

6.2.2 CHARACTERIZE POTENTIALLY EXPOSED POPULATIONS

Characterize the populations on or near the site with respect to location relative to the site, activity patterns, and the presence of sensitive subgroups.

Determine location of current populations relative to the site . Determine the distance and direction of potentially exposed populations from the site. Identify those populations that are closest to or actually living on the site and that, therefore, may have the greatest potential for exposure. Be sure to include potentially exposed distant populations, such as public water supply consumers and distant consumers of fish or shellfish or agricultural products from the site area. Also include populations that could be exposed in the future to chemicals that have migrated from the site. Potential sources of this information include:

- site visit;
- other information gathered as part of the SI or during the initial stages of the RI;
- population surveys conducted near the site;
- topographic, land use, housing or other maps; and
- recreational and commercial fisheries data.

Determine current land use . Characterize the activities and activity patterns of the potentially exposed population. The following land use categories will be applicable most often at Superfund sites:

- residential;
- commercial/industrial; and
- recreational.

Determine the current land use or uses of the site and surrounding area. The best source of this information is a site visit. Look for homes, playgrounds, parks, businesses, industries, or other land uses on or in the vicinity of the site. Other sources on local land use include:

- zoning maps;
- state or local zoning or other land use-related laws and regulations;
- data from the U.S. Bureau of the Census;
- topographic, land use, housing or other maps; and
- aerial photographs.

Some land uses at a site may not fit neatly into one of the three land use categories and other land use classifications may be more appropriate (e.g., agricultural land use). At some sites it may be most appropriate to have more than one land use category.

After defining the land use(s) for a site, identify human activities and activity patterns associated with each land use. This is basically a "common sense" evaluation and is not based on any specific data sources, but rather on a general understanding of what activities occur in residential, business, or recreational areas.

Characterize activity patterns by doing the following.

- Determine the percent of time that the potentially exposed population(s) spend in the potentially contaminated area. For example, if the potentially exposed population is commercial or industrial, a reasonable maximum daily exposure period is likely to be 8 hours (a typical work day). Conversely, if the population is residential, a maximum daily exposure period of 24 hours is possible.
- Determine if activities occur primarily indoors, outdoors, or both. For example, office workers may spend all their time indoors, whereas construction workers may spend all their time outdoors.
- Determine how activities change with the seasons. For example, some outdoor, summertime recreational activities (e.g., swimming, fishing) will occur less frequently or not at all during the winter months. Similarly, children are likely to play outdoors less frequently and with more clothing during the winter months.
- Determine if the site itself may be used by local populations, particularly if access to the site is not restricted or otherwise limited (e.g., by distance). For example, children living in

the area could play onsite, and local residents could hunt or hike onsite.

- Identify any site-specific population characteristics that might influence exposure. For example, if the site is located near major commercial or recreational fisheries or shellfisheries, the potentially exposed population is likely to eat more locally-caught fish and shellfish than populations located inland.

Determine future land use. Determine if any activities associated with a current land use are likely to be different under an alternate future land use. For example, if ground water is not currently used in the area of the site as a source of drinking water but is of potable quality, future use of ground water as drinking water would be possible. Also determine if land use of the site itself could change in the future. For example, if a site is currently classified as industrial, determine if it could possibly be used for residential or recreational purposes in the future.

Because residential land use is most often associated with the greatest exposures, it is generally the most conservative choice to make when deciding what type of alternate land use may occur in the future. However, an assumption of future residential land use may not be justifiable if the probability that the site will support residential use in the future is exceedingly small.

Therefore, determine possible alternate future land uses based on available information and professional judgment. Evaluate pertinent information sources, including (as available):

- master plans (city or county projections of future land use);
- Bureau of the Census projections; and
- established land use trends in the general area and the area immediately surrounding the site (use Census Bureau or state or local reports, or use general historical accounts of the area).

Note that while these sources provide potentially useful information, they should not be interpreted as providing proof that a certain land use will or will not occur.

Assume future residential land use if it seems possible based on the evaluation of the available information. For example, if the site is currently industrial but is located near residential areas in an urban area, future residential land use may be a reasonable possibility. If the site is industrial and is located in a very rural area with a low population density and projected low growth, future residential use would probably be unlikely. In this case, a more likely alternate future land use may be recreational. At some sites, it may be most reasonable to assume that the land use will not change in the future.

There are no hard-and-fast rules by which to determine alternate future land use. The use of professional judgment in this step is critical. Be sure to consult with the RPM about any decision regarding alternate future land use. Support the selection of any alternate land use with a logical, reasonable argument in the exposure assessment chapter of the risk assessment report. Also include a qualitative statement of the likelihood of the future land use occurring.

Identify subpopulations of potential concern. Review information on the site area to determine if any subpopulations may be at increased risk from chemical exposures due to increased sensitivity, behavior patterns that may result in high exposure, and/or current or past exposures from other sources. Subpopulations that may be more sensitive to chemical exposures include infants and children, elderly people, pregnant and nursing women, and people with chronic illnesses. Those potentially at higher risk due to behavior patterns include children, who are more likely to contact soil, and persons who may eat large amounts of locally caught fish or locally grown produce (e.g., home-grown vegetables). Subpopulations at higher risk due to exposures from other sources include individuals exposed to chemicals during occupational activities and individuals living in industrial areas.

To identify subpopulations of potential concern in the site area, determine locations of schools, day care centers, hospitals, nursing homes, retirement communities, residential areas with children, important commercial or recreational fisheries near the site, and major industries potentially involving chemical exposures. Use local census data and information from local public health officials for this determination.

6.3 STEP 2: IDENTIFICATION OF EXPOSURE PATHWAYS

This section describes an approach for identifying potential human exposure pathways at a Superfund site. An exposure pathway describes the course a chemical or physical agent takes from the source to the exposed individual. An exposure pathway analysis links the sources, locations, and types of environmental releases with population locations and activity patterns to determine the significant pathways of human exposure.

An exposure pathway generally consists of four elements: (1) a source and mechanism of chemical release, (2) a retention or transport medium (or media in cases involving media transfer of chemicals), (3) a point of potential human contact with the contaminated medium (referred to as the exposure point), and (4) an exposure route (e.g., ingestion) at the contact point. A medium contaminated as a result of a past release can be a contaminant source for other media (e.g., soil contaminated from a previous spill could be a contaminant source for ground water or surface water). In some cases, the source itself (i.e., a tank, contaminated soil) is the exposure point, without a release to any other medium. In these latter cases, an exposure pathway consists of (1) a source, (2) an exposure point, and (3) an exposure route. Exhibit 6-2 illustrates the basic elements of each type of exposure pathway.

The following sections describe the basic analytical process for identifying exposure pathways at Superfund sites and for selecting pathways for quantitative analysis. The pathway analysis described below is meant to be a qualitative evaluation of pertinent site and chemical information, and not a rigorous quantitative evaluation of factors such as source strength, release rates, and chemical fate and transport. Such factors are considered later in the exposure assessment during the quantitative determination of exposure concentrations (Section 6.5).

6.3.1 IDENTIFY SOURCES AND RECEIVING MEDIA

To determine possible release sources for a site in the absence of remedial action, use all available site descriptions and data from the PA, SI, and RI reports. Identify potential release mechanisms and receiving media for past, current, and future releases. Exhibit 6-3 lists some typical release sources, release mechanisms, and receiving media at Superfund sites. Use monitoring data in conjunction with information on source locations to support the analysis of past, continuing, or threatened releases. For example, soil contamination near an old tank would suggest the tank (source) ruptured or leaked (release mechanism) to the ground (receiving media). Be sure to note any source that could be an exposure point in addition to a release source (e.g., open barrels or tanks, surface waste piles or lagoons, contaminated soil).

Map the suspected source areas and the extent of contamination using the available information and monitoring data. As an aid in evaluating air sources and releases, Volumes I and II of the National Technical Guidance Studies (NTGS; EPA 1989a,b) should be consulted.

6.3.2 EVALUATE FATE AND TRANSPORT IN RELEASE MEDIA

Evaluate the fate and transport of the chemicals to predict future exposures and to help link sources with currently contaminated media. The fate and transport analysis conducted at this stage of the exposure assessment is not meant to result in a quantitative evaluation of media-specific chemical concentrations. Rather, the intent is to identify media that are receiving or may receive site-related chemicals. At this stage, the assessor should answer the questions: What chemicals occur in the sources at the site and in the environment? In what media (onsite and offsite) do they occur now? In what media and at what location may they occur in the future? Screening-level analyses using available data and simplified calculations or analytical models may assist in this qualitative evaluation.

After a chemical is released to the environment it may be:

- transported (e.g., convected downstream in water or on suspended sediment or through the atmosphere);
- physically transformed (e.g., volatilization, precipitation);
- chemically transformed (e.g., photolysis, hydrolysis, oxidation, reduction, etc.);
- biologically transformed (e.g, biodegradation); and/or
- accumulated in one or more media (including the receiving medium).

To determine the fate of the chemicals of potential concern at a particular site, obtain information on their physical/chemical and environmental fate properties. Use computer data bases (e.g., SRC's Environmental Fate, CHEMFATE, and BIODEG data bases; BIOSIS; AQUIRE) and the open literature as necessary as sources for up-to-date information on the physical/chemical and fate properties of the chemicals of potential concern. Exhibit 6-4 lists some important chemical-specific fate parameters and briefly describes how these can be used to evaluate a chemical's environmental fate.

Also consider site-specific characteristics (identified in Section 6.2.1) that may influence fate and transport. For example, soil characteristics such as moisture content, organic carbon content, and cation exchange capacity can greatly influence the movement of many chemicals. A high water table may increase the probability of leaching of chemicals in soil to ground water.

Use all applicable chemical and site-specific information to evaluate transport within and between media and retention or accumulation within a single medium. Use monitoring data to identify media that are contaminated now and the fate pathway analysis to identify media that may be contaminated now (for media not sampled) or in the future. Exhibit 6-5 presents some important questions to consider when developing these pathways. Exhibit 6-6 presents a series of flow charts useful when evaluating the fate and transport of chemicals at a site.

6.3.3 IDENTIFY EXPOSURE POINTS AND EXPOSURE ROUTES

After contaminated or potentially contaminated media have been identified, identify exposure points by determining if and where any of the potentially exposed populations (identified in Step 1) can contact these media. Consider population locations and activity patterns in the area, including those of subgroups that may be of particular concern. Any point of potential contact with a contaminated medium is an exposure point. Try to identify those exposure points where the concentration that will be contacted is the greatest. Therefore, consider including any contaminated media or sources onsite as a potential exposure point if the site is currently used, if access to the site under current conditions is not restricted or otherwise limited (e.g., by distance), or if contact is possible under an alternate future land use. For potential offsite exposures, the highest exposure concentrations often will be at the points closest to and downgradient or downwind of the site. In some cases, highest concentrations may be encountered at points distant from the site. For example, site-related chemicals may be transported and deposited in a distant water body where they may be subsequently bioconcentrated by aquatic organisms.